Hybrid Electrochemistry-Advanced Combustion for High Efficiency Distributed Power

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Project Vision:

Design a hybrid SOFC-IC engine system and optimize the BOP components for 70%+ system efficiency. Key developments: high pressure stack and spark-ignition engine that uses anode tailgas as the fuel.

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Project Overview

Fed. funding:	$2.325M
Length	24 mo.

Team member	Location	Role in project
Stony Brook University	Stony Brook, NY	Demonstrate advanced combustion with tailgas, design multi-cylinder engine, model hybrid system for design
Nexceris	Lewis Center, OH	Develop high pressure SOFC stack, provide stack boundary conditions and tailgas composition
Czero	Fort Collins, CO	Fabricate multi-cylinder engine and demonstrate its capability to operate in a low temperature combustion mode
Brookhaven National Laboratory	Upton, NY	Hybrid system thermal integration and component selection

Context/history of project

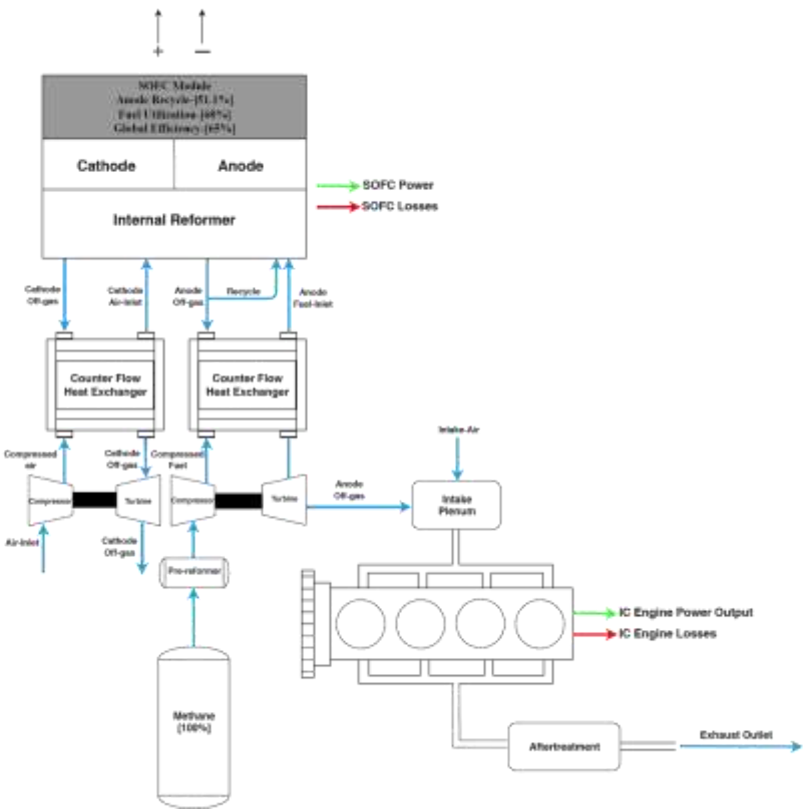
New collaboration in the INTEGRATE framework

All groups have previous involvement with ARPA-E

Innovation and Objectives

Innovation

Combination of high pressure SOFC with internal combustion engine. How?



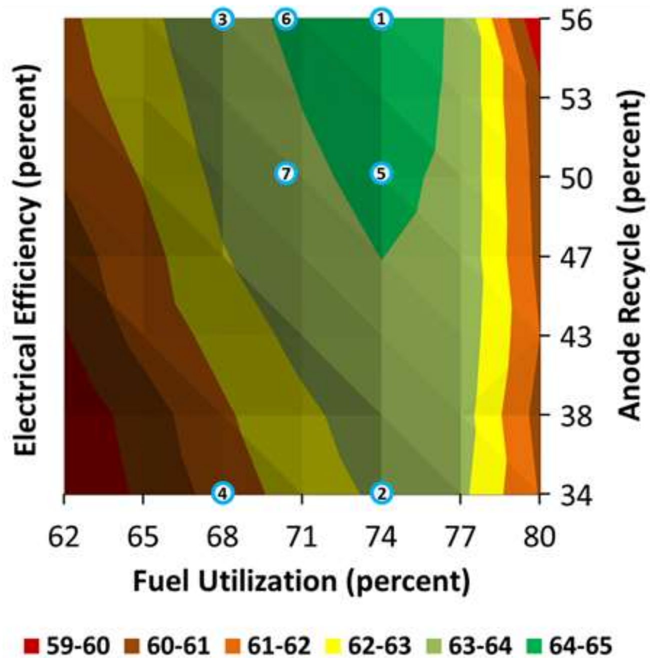
Task outline, technical objectives

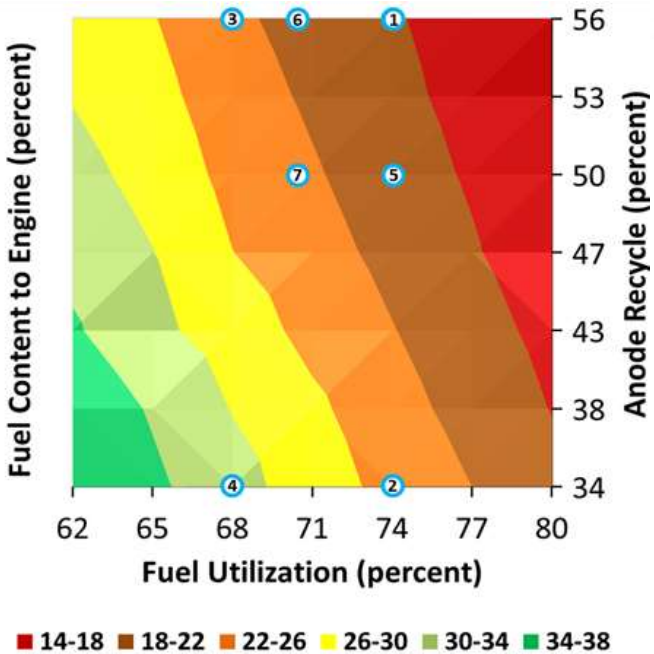
- Co-develop a pressure tolerant SOFC and a spark-ignition engine to use the tailgas as fuel
- Model and conceptually design a hybrid system for 100 kWe power output and maximum efficiency

Tech-to-Market objectives

- Target markets for continuous, distributed power generation
- Early adopters: data centers, remote building main power, military sites with logistically available fuels
- SOFC manufacturing dominant challenge, additional components already available

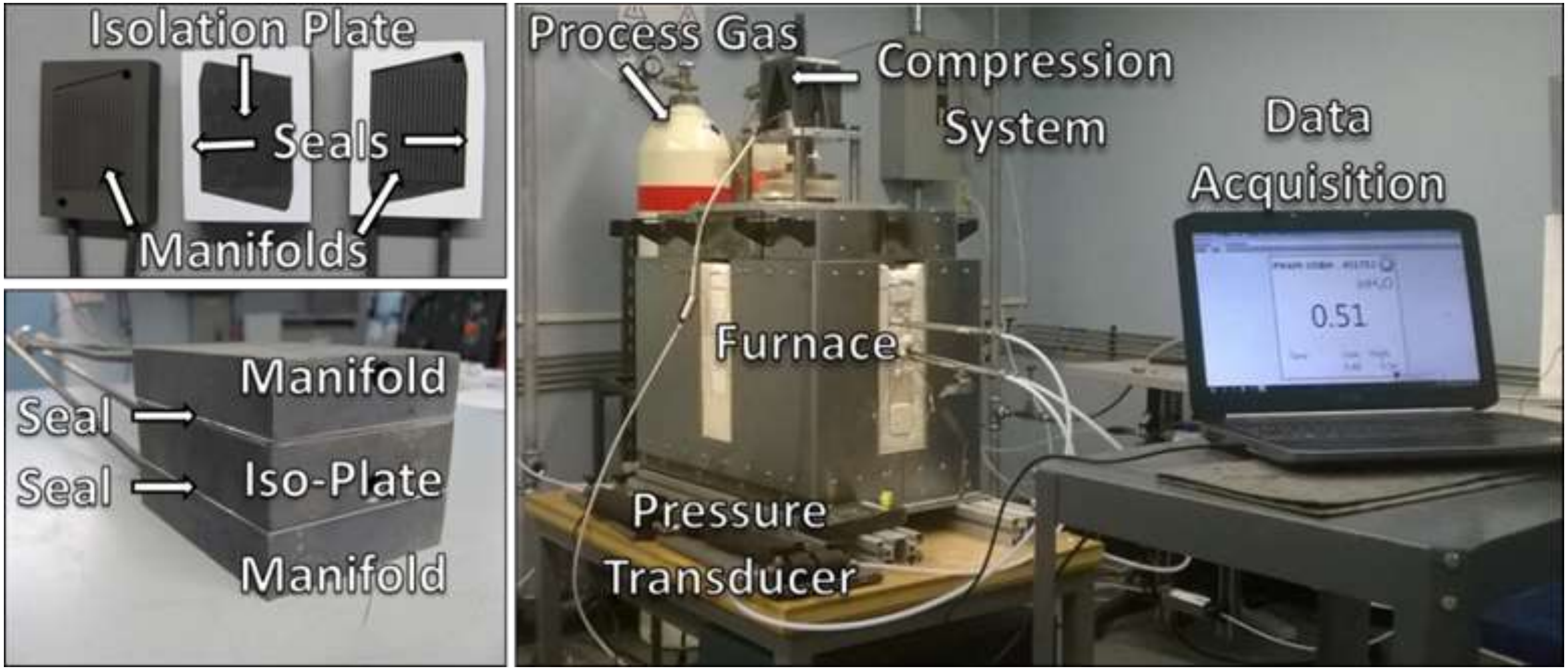
Stack Performance Mapping





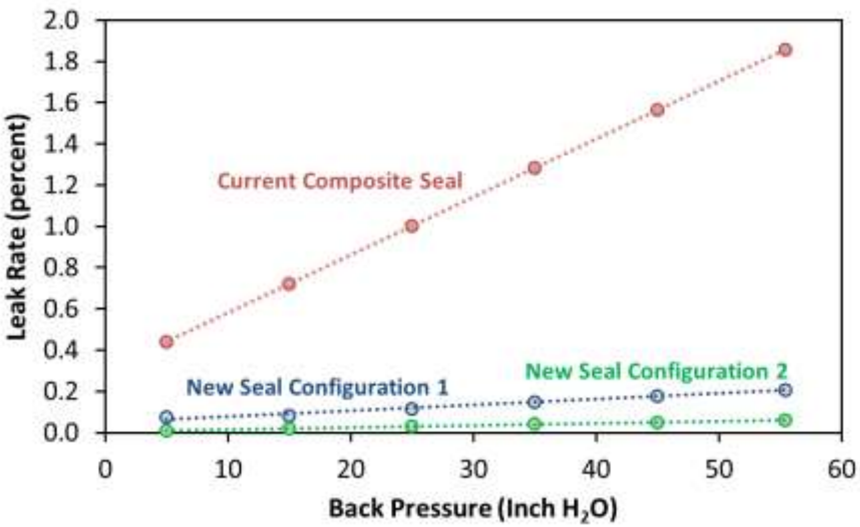
- Mapping based on model validated by experimental data
- Objective: understand stack performance over a range of operating conditions in order to maximize the tailgas energy content without sacrificing efficiency

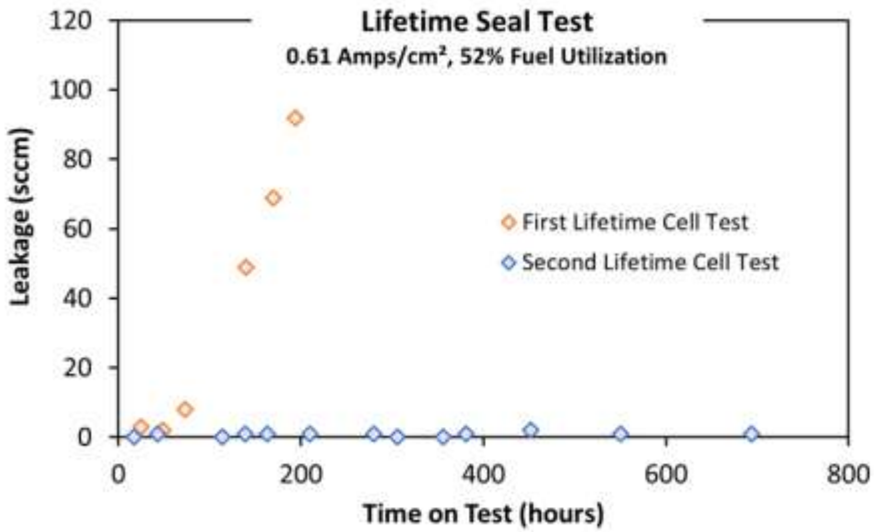
Seal Material Development and Validation



- Objective: 10X improvement in stack sealing capability, compared to current baseline seals, demonstrated via offline testing with target leak rate of < 0.05%
- Nexceris' ambient pressure offline seal testing apparatus shown above

Seal Material Development and Validation





- Data comparing new seal configuration to Nexceris' original composite seal: leak rates near the target after 10 thermal cycles (offline seal testing)
- Modifications to seal configuration enabled long-term stability in relevant "operating cell" environment
- The experimental setup has been modified and validated for testing at elevated pressure

CHANGING WHAT'S POSSIBLE

Engine Displacement Study

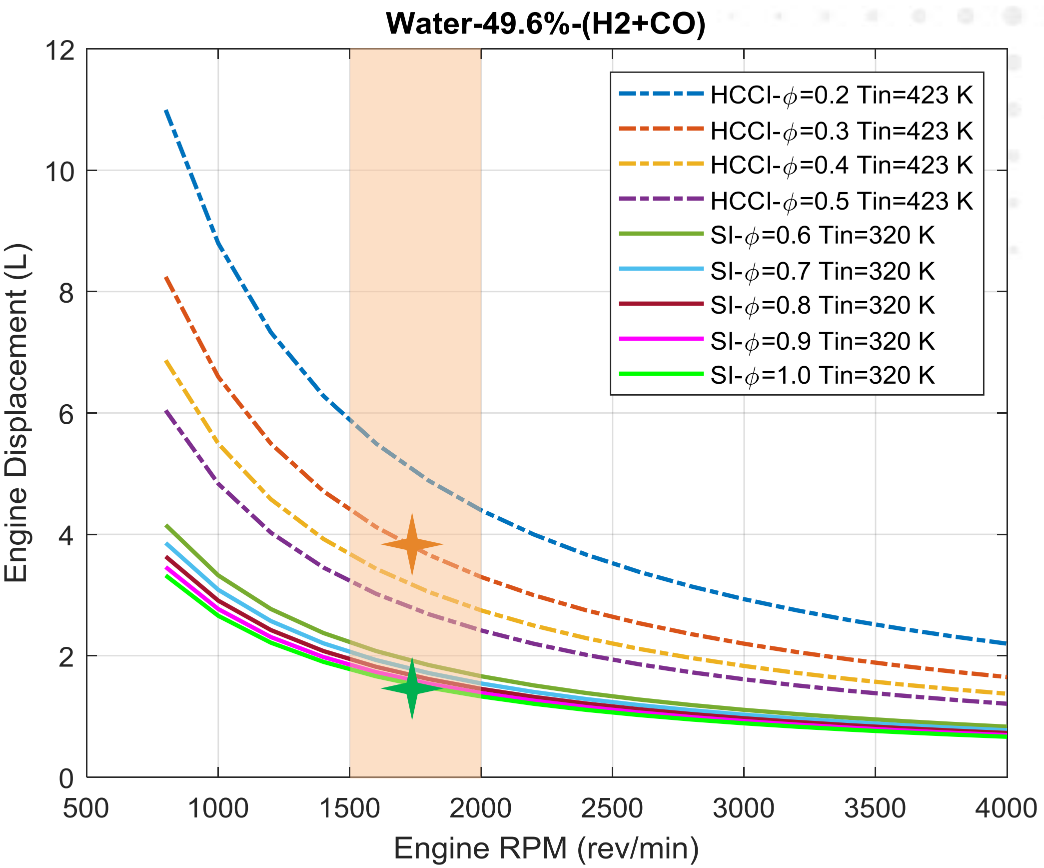
- Baseline tailgas composition:

  17.1% H_2

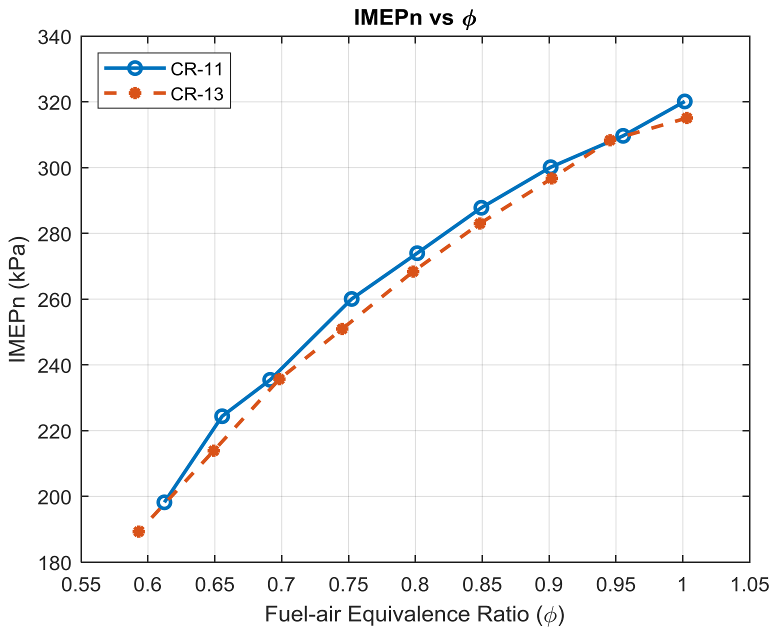
  7.9% CO

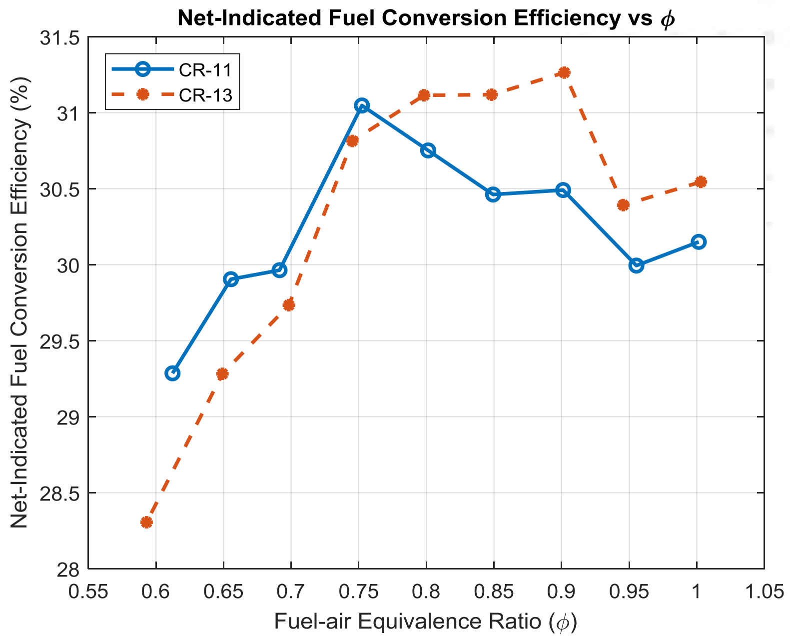
  25.4% CO_2

  49.6% H_2O
- Engine displacement calculations are based on 49.6% of water vapor content
- Displacement is reduced as the engine speed is increased
- Increasing the equivalence ratio also decreases engine displacement
- HCCI combustion mode requires larger engine displacement than SI mode at the same engine speed



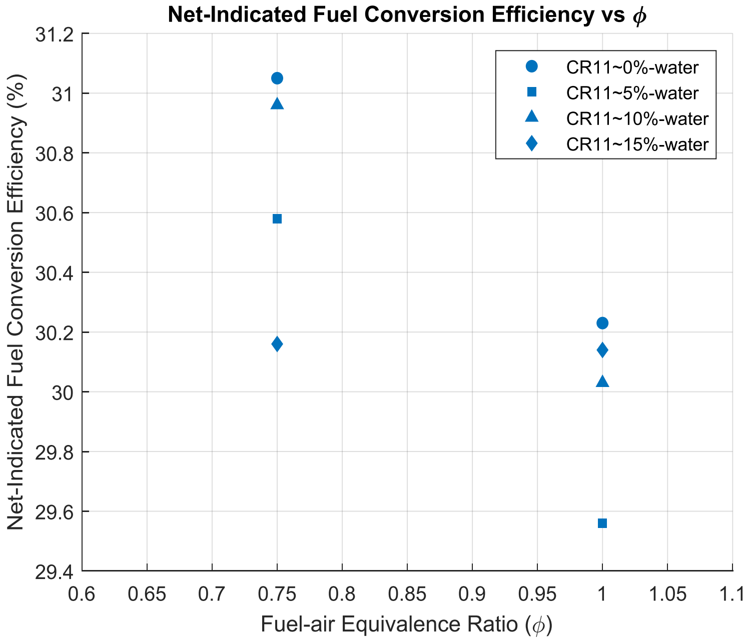
Engine Experimental Testing

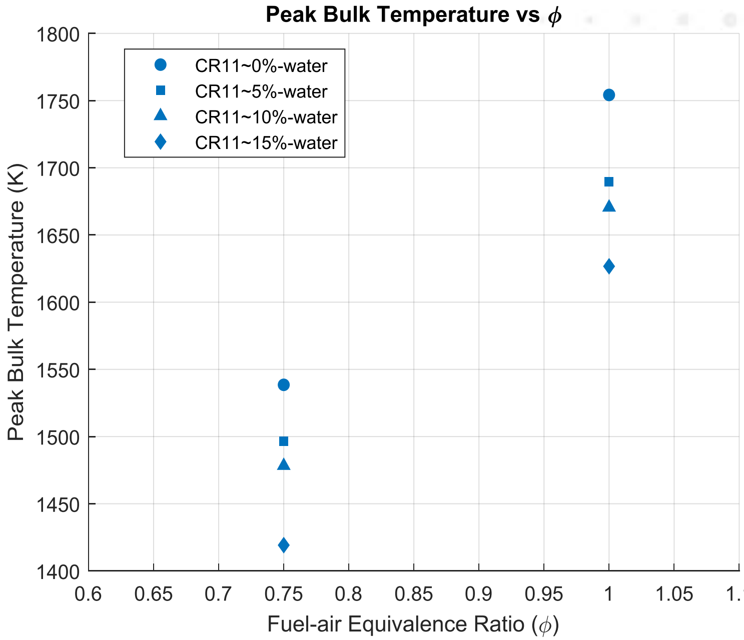




- Engine experimental testing in SI mode with dry tailgas showed good combustion characteristics, load, and net indicated efficiency
- Low CO (20 – 50 g/kg fuel) and low NOx (0.2 – 1 g/kg fuel)

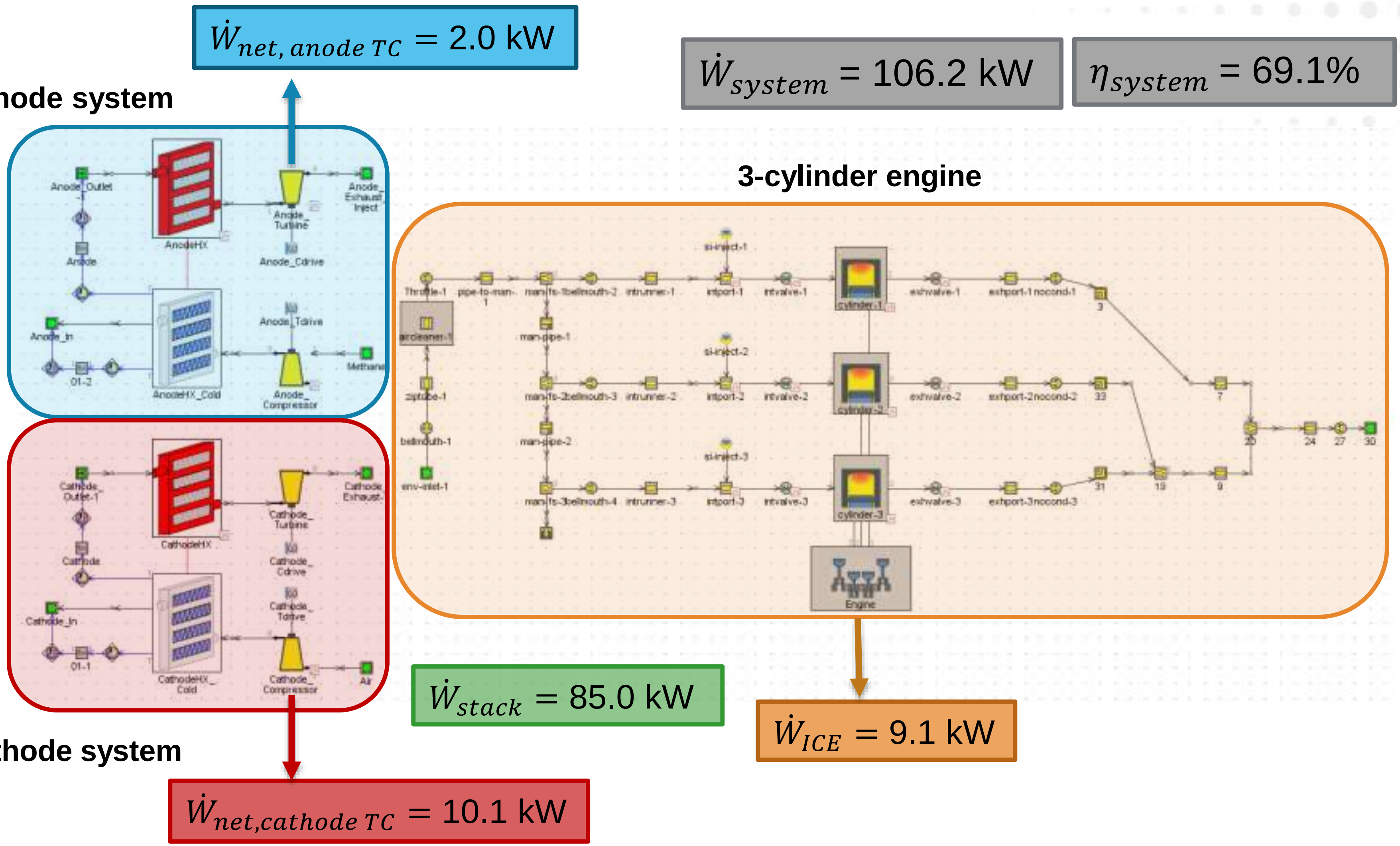
Effects of H_2O Content in Tailgas





- Experimental testing with water addition showed that the extra dilution resulted in reduced heat release, work production, and efficiency
- Also lower cylinder temperatures and NOx emissions at the expense of combustion efficiency

Hybrid System Modeling



Market Applications

- Potentially attractive markets and applications:
  - Power for data centers
  - Remote building continuous or backup power (start-up time?)
  - Military applications for remote power with logistically available fuels
  - Long-haul trucks

- Requirements:
  - High efficiency and low emissions
  - Reasonable capital cost
  - Reliability and low operating cost

Risks

- Design of heat exchanger systems for the cathode and anode
  - Mitigation: modeling and analysis to understand boundary conditions for heat exchangers, effectiveness, and associated cost

- Complexity of hybrid system to maximize efficiency
  - Mitigation: perform detailed system modeling and analysis to understand the trade-off between component complexity and overall efficiency
    - Validate modeling components against experimental data

- Economics of hybrid system
  - Mitigation: analyze the trade-off between component design, complexity, and capital/operating cost

Thank you!